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Nuclear Structure of the Cd and Te Nuclei: Akin to Tin or a Breed Apart?[1]

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Abstract. Many of the $_{48}$Cd nuclei are good examples of U(5) or vibrational nuclei. Like the $_{50}$Sn nuclei and others in the region, states exist which are interpreted in terms of the excitation of a pair of protons across the shell gap (intruders). The features of the comparatively well-understood Cd nuclei will be considered and compared with the $_{52}$Te nuclei where intruders have not been identified experimentally and problems exist with the U(5) interpretation.

Underlying vibrational structure

The Cd nuclei have been referred to as "the paragons of nuclei exhibiting the U(5) symmetry" [1], *i.e.*, a vibrational structure, and this is particularly true in the middle of the shell. The simple U(5) limit of the interacting boson model (IBM), with just four parameters to describe the energies of the levels, provides a reasonable description of many of the Cd nuclei.

Intruder states

The simple IBM picture does not describe all the positive-parity states. Additional states forming a rotational band have been identified in many nuclei and have been explained as "intruder" states involving the excitation of a pair of protons across the shell gap [2]. The promoted protons, being higher in energy, interact more with the valence neutrons driving the nucleus towards deformation and producing a band of states based on this deformed configuration. Such states have been observed in the tin isotopes, and many other nuclei in that region and are described in the IBM framework using the O(6) dynamical symmetry. Recently, an analytical model to describe this shape-coexistence model has been developed [3], and these authors have used it to describe some of the Cd nuclei. The normal and intruder configurations mix and one of the main features of the U(5)-O(6) model is

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the relatively strong mixing of the two first excited 0^+ levels [3] leading to almost equal amplitudes in the wavefunction.

Octupole vibrations

In addition to the normal vibrational states and the intruder configuration, negative-parity states based on an octupole vibration occur. The 3_1^- state is assumed to be a pure octupole and a quintet of quadrupole-octupole coupled states is expected at an energy which is roughly the sum of the 2_1^+ and 3_1^- states. The search for such states in ^{112}Cd has been the focus of recent efforts [4,5]. Garrett *et al.* [5] have highlighted the need for transition rates in the study of such states. They also consider the discrepancies between the calculated and measured *E1* rates and point out that the spdf-IBM and sdf-IBM, whilst successfully calculating *allowed E2* transition rates, are rather poor at predicting the *forbidden E1* transitions which depend on the underlying microscopic structure of the bosons [5].

Mixed-symmetry states

Another point of interest has been the so-called "mixed-symmetry states" that are states which are not symmetric with respect to interchange of protons and neutrons. Such states cannot be described by the IBM-1 which does not distinguish protons from neutrons, but may be treated in the IBM-2 framework. Such states have been identified in ^{112}Cd [6].

The anomalous 2_1^+ energy

Kern *et al.* [7] have reported that the energy of the 2_1^+ state is consistently lower than that predicted by vibrational models based on the energies of the multiphonon states. These authors note that the cause of the observed anomaly has yet to be found [7].

Higher multiphonon states

Another open question is the extent to which the phonon interpretation remains valid as the number of phonons increase. Kern *et al.* [1] report that the phonon model remains valid even beyond the four-phonon states. Indeed, Piiparinen *et al.* [8] have considered transition rates in ^{110}Cd which show a vibrational behaviour up to $I^\pi = 10^+$ (i.e. a 5-phonon state).

The tellurium isotopes

As the tellurium isotopes are 2 protons above the tin shell closure and cadmium is 2 proton-holes from Z=50, some similarities are expected. Although many of the Te isotopes do exhibit features similar to the Cd nuclei, there are also some key differences. Firstly, the 6_1^+ state does not show the same variation across the shell as the other 3-phonon states, indicating that it may have a significant two-proton component [9]. This has motivated semi-microscopic descriptions in the framework of the particle-core coupled model (PCM) [10], and Heyde [11] has suggested that a version of the PCM involving two cores may improve these results.

Secondly, the absence of experimentally identifiable intruder states makes any model involving intruders rather controversial. Nevertheless, IBM-2 calculations by Rikovska *et al.* [12] do seem to indicate that a model including intruder states provides a better description of the 0_3^+ state than one without.

It has also been suggested that the Te nuclei exhibit γ-softness [13] and IBM calculations have been performed for ^{124}Te [14] which use a U(5) symmetry with a small admixture of O(6) and an intruder configuration similar to that of Rikovska *et al.* [12]. So far this seems to be closest to the experimental data for ^{124}Te, but it is not completely satisfactory, especially for the negative-parity states.

The lower mass Te nuclei would seem to be better candidates for vibrational nuclei [15], but here the experiments are complicated by γ rays from unstable nuclei in the mass region.

If the problem of the Te isotopes is to be resolved, new experimental data across the shell are required. To this end, a series of experiments involving the authors of this work is in progress, including, where possible, (α,2nγ), (n,n$'\gamma$) and radioactive decay experiments. The systematic use of complementary techniques for studying the same nucleus has proved to be an extremely powerful method of investigating the Te nuclei. In particular, $\gamma\gamma$-coincidences following β-decay, a reaction frequently neglected in recent years, has yielded exceptionally useful data and is especially interesting when the decaying isotopes are produced using heavy-ion reactions which were not available at the time when β-decay studies were more common.

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